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METEOROLOGICAL MODELS FOR APPLICATION TO ACOUSTIC RAY TRACING I--ETC(U)
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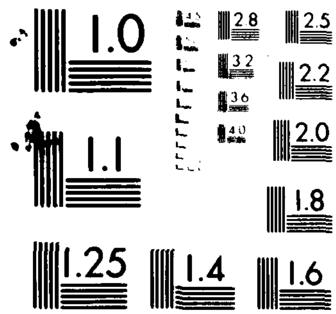

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

INTERIM REPORT TO
ATMOSPHERIC SCIENCES LABORATORY
WHITE SANDS MISSILE RANGE
ON CONTRACT NO. DAA07-80-C-0001
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METEOROLOGICAL MODELS FOR APPLICATION TO ACOUSTIC RAY TRACING IN THE ATMOSPHERE

by Edward V. Welser

SUBMITTED BY:
NOISE CONTROL LABORATORY

APRIL 1980

THE PENNSYLVANIA STATE UNIVERSITY
College of Engineering
Department of Mechanical Engineering
University Park, Pennsylvania

Interim Report to

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The Pennsylvania State University

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I. Introduction

Sound propagation in the atmosphere is affected by vertical temperature and wind gradients. These gradients produce a refracting medium in which sound speed is a function of height. A single sound speed profile as a function of height above the ground can be obtained from individual temperature and wind gradients via empirically derived equations or measured directly or indirectly with sounders. The temperature and wind effects can, therefore, be considered collectively, for acoustic purposes, as a variation of sound speed with height.

A mathematical sound ranging model must effectively incorporate vertical sound velocity gradients. The computer programs developed to model sound propagation using ray techniques presented by Roth[1] require as input either the vertical temperature and wind profiles or the vertical sound velocity profile.

It is assumed that current meteorological vertical temperature and wind velocity profiles will be utilized in the sound propagation model. However, when current meteorological data are unavailable, models[2] that have been developed to extend limited surface temperature and wind conditions vertically may be of value. This report presents several temperature and wind profile models and suggestions for their use.

II. Wind Models

1. Power Wind Law

The power law is often used by engineers to portray the vertical wind profile (p-profile theory):

$$\frac{U_2}{U_1} = \left(\frac{Z_2}{Z_1}\right)^p$$

where U_1 is the wind speed at the anemometer height Z_1, and U_2 is the predicted wind speed at height Z_2. The power p is taken to be constant with height in

a given range. Different values of p should be chosen depending on the height range over which the power law is applied.

A useful method for estimating p can be derived from:

$$p = 1/\ln (Z/Zo)$$

where, in practice, one chooses Z as the geometric mean height in the layer to which the power law profile is to be applied. Zo is the roughness length which, according to Wagner[3] varies from 1×10^{-5}m for a mud flat to 2.83m for a fir forest. For example, in smooth terrain (Zo=0.01m) in a layer of mean height 10m, p is about 1/7, a value commonly suggested in engineering books. But, over rough terrain (Zo=1m, Z=10m), p is much larger.

According to Hans A. Panofsky[4], the p - profile theory for wind profiles does not fit very well when the terrain is uniform and mechanical turbulence prevales. Even then, a power law can be fitted reasonably well over a small height range. The use of p - theory does not permit variation of wind direction with height.

2. Logarithmic wind law

Like the power law, the logarithmic wind law for modeling the vertical structure of the wind applies only in the lowest turbulent layer. Hess[5] defines the logarithmic wind law:

$$U = \frac{U^*}{k} \ln \frac{Z}{Zo}$$

where k is a pure number called the Von Karmen constant and Zo is the roughness parameter. Von Karmen's constant is nondimensional and has been found to be approximately 0.4. U*, the friction velocity, may be approximated, according to Blackadar[6], by:

$$U^* = k\, U_{SFC} \left[\ln \frac{Za}{Zo}\right]^{-1}$$

where U_{SFC} is the surface wind speed and Za is the height of the anemometer.

When the lapse rate is not neutral, the logarithmic wind law is not a

good description of the wind profile. However, even through the real atmosphere is seldom neutral, it has been demonstrated that the logarithmic wind law tends to give more realistic results than the power law in the lowest turbulent layer which is normally less than 100m thick.

3. Ekman Layer Model

Above 50 to 100m the assumption that the turbulent stress is independent of height is no longer valid. Observations demonstrate that the stress decreases with height until it becomes negligible and the wind responses primarily to the pressure-gradient and the coriolis force. This height is called the gradient level and is found near 1000m.

Hess[5] derives the equations:

$$u = Ig(1-e^{-aZ} \cos aZ)$$

$$v = Ug\ e^{-aZ} \sin aZ$$

where Ug is the geostrophic wind speed and $a = \sqrt{f/2K}$.
K is a constant and is approximately $5 \times 10^4\ cm^2\ sec^{-1}$ in the middle latitudes.

The consequence of these equations is that they demonstrate that as the wind turns in response to the trigonometric terms of the equations, the amplitude of these terms decrease exponentially. Thus the wind speed and direction converge rapidly on the geostrophic values.

III. Vertical Temperature and Wind Profile Model

A number of models exist to compute the vertical distribution of temperature and wind with height. Reference 2 lists a number of vertical wind profile models available at ASL. Blackadar[6] presents another model which incorporates a routine to compute the vertical distribution of wind with height suitable to a neutral temperature profile with the same potential temperature as the surface temperature. The Blackadar routine was modified to include the power wind law as an option. Inputs to the model include the temperature lapse rate

(°C/m), average height of obstructions (m), surface wind speed (m/s) at some height (m), latitude (DEG), and the vector difference between the surface wind and the thermal wind (m/s).

The model approximates the roughness length by:

$$Zo \approx AVEHGT/30.0$$

where AVEHGT is the average height of the obstructions in meters. The friction velocity is approximated by:

$$U^* = 0.4 * SFCWS \; [\ln (ANEMO/Z_o)]^{-1}$$

where SFCWS is the surface wind speed at the anemometer height, (ANEMO).

For barothropic conditions, the vector difference between the surface wind and the thermal wind is zero. The X component of the vector is taken to be in the same direction as the surface wind. The angle between the surface wind vector and the thermal wind vector will be defined as B. A surface meteorological chart or forecast of thermal winds for the time and place in question is assumed to be available. In many instances the atmosphere is essentially barothropic and in those cases only small errors will be introduced if VDIF, the vector difference, is set to zero.

The Blackadar model utilizes the logarithmic wind law in the friction layer and the Ekman layer model in the planetary boundary layer. The proposed model predicts temperature and wind at 50m intervals up to 1000m which is the approximate height of the planetary boundary layer in mid-latitudes.

IV. Proposed Use of the Temperature and Wind Profile Model

The temperature at the surface and temperature lapse rate are inputs to the model for determining the vertical temperature distribution. The default condition on the temperature lapse rate is 0.0065°C/m.

The surface wind, roughness length, friction velocity, thermal winds, and latitude are input to the model for determining the vertical distribution of wind speed, u and v component, with height.

For use of the power law model, only the temperature at the surface, temperature laps rate, surface wind speed, height of the anemometer, and average height of the obstructions need be entered. The selection switch (NSWTCH) variable must be non-zero if this option is selected.

Table 1 and Table 2 provide examples of the subroutine output given realistic values for surface wind (4.76 mile/hr and 9.51 mile/hr) and temperature (10°C). Given the specified initial parameters, which included VDIF and B, a driver program called the proposed subroutine to compute the vertical temperature and vertical wind profile using the power law and the modified Blackadar routine.

The power law and modified Blackadar routines calculated reasonable values for the variation of wind with height. The Blackadar routine did produce values for the wind that were about twice as large as the power law results at 1000 m for the cases tested. Since Blackadar utilized equations which have trignometric terms, the resultant wind does turn with height.

The inclusion of the vector difference term demonstrates the effect it has on the model output. The test case of 30° shows a slight increase in the U component of the wind at all levels compared to the corresponding barotrophic level.

Appendix 1 provides a computer listing of the proposed model and Appendix 2 defines the model's input variables.

TABLE 1

Subroutine Test Results Given a Friction Velocity of 0.25 and Roughness Parameter of 0.1

Input Parameters:

OLAT = 40.0 SFCWS = 2.126 M/S
TEMP = 10.0 ANEMO = 3.0 M
DELT = 0.0065 AVEHGT = 3.0 M

		WINDS (M/S)					
		POWER LAW		MODIFIED BLACKADAR			
				VDIF = 0.0 B = 0.0		VDIF = 1.5 B = 30.0	
HEIGHT (M)	TEMP (°C)	U (M/S)	V (M/S)	U (M/S)	V (M/S)	U (M/S)	V (M/S)
25.0	9.84	2.67633	0.00000	3.45132	0.00000	3.45132	0.00000
75.0	9.51	3.01538	0.00000	4.48661	-0.25090	4.48827	-0.24658
125.0	9.19	3.18734	0.00000	5.29716	-0.34377	5.30482	-0.32687
175.0	8.86	3.30594	0.00000	5.90503	-0.50770	5.92371	-0.47193
225.0	8.54	3.39739	0.00000	6.33695	-0.71951	6.37171	-0.66035
275.0	8.21	3.47222	0.00000	6.62257	-0.95843	6.67819	-0.87288
325.0	7.89	3.53577	0.00000	6.79149	-1.20702	6.87224	-1.09334
375.0	7.56	3.59114	0.00000	6.78131	-1.45162	6.98081	-1.30900
425.0	7.24	3.64027	0.00000	6.88640	-1.68223	7.02763	-1.51058
475.0	6.91	3.68449	0.00000	6.85736	-1.89219	7.03264	-1.69191
525.0	6.59	3.72475	0.00000	6.80089	-2.07766	7.01196	-1.84948
575.0	6.26	3.76173	0.00000	6.72995	-2.23714	6.97805	-1.98194
625.0	5.94	3.79593	0.00000	6.65415	-2.37083	6.94010	-2.08955
675.0	5.61	3.82779	0.00000	6.58024	-2.48021	6.90450	-2.17377
725.0	5.29	3.85760	0.00000	6.51255	-2.56754	6.87535	-2.23680
775.0	4.96	3.88564	0.00000	6.45358	-2.63554	6.85496	-2.28125
825.0	4.64	3.91210	0.00000	6.40438	-2.68710	6.84426	-2.30991
875.0	4.31	3.93717	0.00000	6.36502	-2.72507	6.84320	-2.32549
925.0	3.99	3.96100	0.00000	6.33485	-2.75209	6.85115	-2.33054
975.0	3.66	3.98370	0.00000	6.31284	-2.77056	6.86704	-2.32735

TABLE 2

Subroutine Test Results Given a Friction Velocity of 0.5 and Roughness Parameter of 0.1

Input Parameters:

OLAT = 40.0	DEG		SFCWS = 4.251	M/S
TEMP = 10.0	°C		ANRMU = 3.0	M
DELT = 0.0065	°C/M		AVEHGT = 3.0	M

		WIND					
		POWER LAW		MODIFIED BLACKADAR			
				VDIF = 0.0, B = 0.0		VDIF = 1.5, B = 30.0	
HEIGHT (M)	TEMP (°C)	U (M/S)	V (M/S)	U (M/S)	V (M/S)	U (M/S)	V (M/S)
25.0	9.84	5.35140	0.00000	6.90101	0.00000	6.90101	0.00000
75.0	9.51	6.02935	0.00000	8.33166	-0.48419	8.33179	-0.48378
125.0	9.19	6.37319	0.00000	9.36418	-0.48306	9.36592	-0.47828
175.0	8.86	6.61032	0.00000	10.28351	-0.53223	10.28893	-0.51869
225.0	8.54	6.79318	0.00000	11.09333	-0.62590	11.10474	-0.59970
275.0	8.21	6.94280	0.00000	11.79865	-0.75807	11.81853	-0.71585
325.0	7.89	7.06988	0.00000	12.40554	-0.92277	12.43644	-0.86162
375.0	7.56	7.18058	0.00000	12.92078	-1.11415	12.96525	-1.03161
425.0	7.24	7.27883	0.00000	13.35161	-1.32665	13.41217	-1.22067
475.0	6.91	7.36726	0.00000	13.70552	-1.55505	13.78462	-1.42396
525.0	6.59	7.44776	0.00000	13.99005	-1.79453	14.09004	-1.63702
575.0	6.26	7.52169	0.00000	14.21266	-2.04072	14.33573	-1.85578
625.0	5.94	7.59008	0.00000	14.38057	-2.28975	14.52880	-2.07663
675.0	5.61	7.65377	0.00000	14.50072	-2.53818	14.67600	-2.29639
725.0	5.29	7.71338	0.00000	14.57965	-2.78308	14.78371	-2.51233
775.0	4.96	7.76944	0.00000	14.62346	-3.02195	14.85788	-2.72212
825.0	4.64	7.82236	0.00000	14.63781	-3.25273	14.90397	-2.92386
875.0	4.31	7.87250	0.00000	14.62783	-3.47378	14.92700	-3.11602
925.0	3.99	7.92014	0.00000	14.59819	-3.68380	14.93143	-3.29741
975.0	3.66	7.96553	0.00000	14.55307	-3.88186	14.92132	-3.46717

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APPENDIX 1

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LISTING      04-29-80

          SUBROUTINE WCTEMP(KSWTCH,CLAT,TEMP,DELT,SFCWS,ANEMO,AVEHGT,VDIF,B)
C         PROGRAM TO CALCULATE TEMPERATURE AND WIND PROFILES
C         USING A MODIFIED VERSION OF BLACKADAR'S ROUTINE
C
C         EKMAN LAYER MODEL TO CALCULATE WIND PROFILE GIVEN FRICTION
C         VELOCITY, ROUGHNESS LENGTH, LATITUDE, SURFACE TEMPERATURE,
C         SURFACE WIND, AND SCALED HEIGHT OF THE SURFACE LAYER
C         CLAT (DEG)      LATITUDE OF AREA
C         AVEHGT (M)      AVERAGE HEIGHT OF OBSTRUCTIONS
C         SFCWS (M/S)     SURFACE WIND SPEED
C         ANEMO (M)       HEIGHT OF THE ANEMOMETER
C         VDIF (M/S)      SURFACE WIND VECTOR MINUS THE THERMAL WIND
C         B (DEG)         ANGLE BETWEEN THE SURFACE WIND VECTOR AND THE THERMAL
C                         WIND VECTOR
C         TEMP ( C)       SURFACE TEMPERATURE
C         DELT            TEMPERATURE LAPSE RATE
C
          COMMON U(20),V(20),T(20),ZHT(20),ZED(40),Z(20)
C         BE = SCALED HEIGHT OF THE SURFACE LAYER
          BE=0.01
C         BETA = U,V COMPONENT OF THE UH-UG VECTOR
          BETA=11.18
C
          VK=0.4
          VK2=VK**2.0
        1 DZ=50.
          ZTH=DZ/2.0
          ZHT(1)=ZTH
          B=B/57.296
          SX=0.0
          SY=0.0
          ZZERO=AVEHGT/30.0
          USTR=0.4*SFCWS/ALOG(ANEMO/ZZERO)
          IF(VDIF.EQ.0.0) GO TO 2
          SX=VDIF*COS(B)
          SY=VDIF*SIN(B)
        2 IF(DELT.NE.0.0) GO TO 3
          DELT=0.0065
        3 CONTINUE
          IF(USTR.LE.0.0) GO TO 199
          WRITE(6,11)CLAT,USTR,ZZERO,TEMP,SX,SY
          F=1.414E-04 * SIN(CLAT/57.296)
          ZED(1)=(ZTH*F)/USTR
       60 DO 65 I=2,20
          ZHT(I)=ZHT(I-1)+DZ
          ZED(I)=(ZHT(I)*F)/USTR
          Z(1)=DZ/2.0
          Z(I)=Z(I-1)+DZ
       65 CONTINUE
          IF(KSWTCH.NE.0) GO TO 5
       90 DO 95 I=1,20
C         TEMPERATURE CALCULATED FROM INPUT LAPSE RATE
C         DEFAULT CONDITION IS THE DRY ADIABATIC LAPSE RATE 0.0065 (C/M)
          T(I)=TEMP-DELT*ZHT(I)
          IF(ZED(I).GT.0.01) GO TO 91
C         WITHIN SURFACE LAYER CALCULATE LOGRITHMIC PROFILE
```

APPENDIX 1

LISTING 04-29-80

```
      U(I)=(USTR/VK)*ALOG(ZHT(I)/ZZERO)
      V(I)=0.0
      GO TO 95
   91 CONTINUE
C     SX,SY ARE U,F* THE THERMAL WIND OR THE GEOSTROPHIC WIND SHEAR
C     DUE TO BAROCLINICITY
      U0=-BETA+(SX+SY)/(2.0*BETA*VK2)
      V0= BETA-(SX-SY)/(2.0*BETA*VK2)
      TERM1=(1.0/VK)*ALOG(0.01*USTR/(F*ZZERO))
     1-U0+(SX/VK2)*(ZED(I)-BE)
      TERM2= EXP(-BETA*(ZED(I)-BE))
      TERM3=(U0*COS(BETA*(ZED(I)-BE))
     1+V0*SIN(BETA*(ZED(I)-BE)))
      U(I)=(TERM1+TERM2*TERM3)*USTR
      TERM1 = -V0+(SY/VK2)*(ZED(I)-BE)
      TERM3=(V0*COS(BETA*(ZED(I)-BE))-U0
     1*SIN(BETA*(ZED(I)-BE)))
      V(I)=(TERM1+TERM2*TERM3)*USTR
   95 CONTINUE
   96 DO 100 I=1,20
      WRITE(6,99) I,ZHT(I),T(I),U(I),V(I)
  100 CONTINUE
      RETURN
    5 P=1.0/ALOG(1000.0/ZZERO)
      DO 6 I=1,20
      T(I)=TEMP-DELT*ZHT(I)
      U(I)=SFCWS*(ZHT(I)/ANEMO)**P
      V(I)=0.0
    6 CONTINUE
      GO TO 96
   11 FORMAT('0',2X,'LAT=',F10.4,5X,'USTR=',F10.4,5X,'ZZERO=',F10.4,5X,
     1'TEMP=',F10.4,2X,'  SX=',F10.4,5X,'SY=',F10.4)
   99 FORMAT(' ',I3,F10.1,F10.2,2F10.5)
  199 STOP
      END
```

APPENDIX 2

MODEL INPUT PARAMETERS

SYMBOL	DIMENSION	DESCRIPTION
OLAT	DEG	Latitude
TEMP	°C	Surface temperature
DELT	°C/m	Temperature lapse rate
SFCWs	m/s	Surface wind speed
ANEMO	m	Height of anemometer
AVEHGT	m	Average height of obstructions
VDIF	m/s	Vector difference of wind speed minus thermal wind
B	DEG	Angle between surface wind and thermal wind
KSWTCH		Model selector switch